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Soil Salinity and Heavy Metal Contamination in Soil: Impacts on Ecosystem Sustainability in Kurugu, Gombe State, Nigeria

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ABSTRACT

Soil salinity and Heavy metal contamination are key conservational challenges that disturb farming output besides environmental sustainability. This study examines the impact of soil salinization and heavy metal contamination accumulation on different land uses in Kurugu, Kwami Local Government Area, Gombe State, Nigeria. A total of 42 composite samples of soils were collected and analyzed for key physicochemical parameters, including pH, electrical conductivity (EC), bulk density, organic matter (OM), and organic carbon (OC). Additionally, heavy metal concentrations of arsenic (As), copper (Cu), cadmium (Cd), chromium (Cr), and lead (Pb) were examined. The findings revealed that soil pH ranged from 6.87 to 7.99, while EC values varied between 137 and 915 µS/cm, signifying fluctuations in salinity levels. Bulk density ranged from 1.18 to 1.74 g/cm³, OM content varied between 3.26% and 4.50%, and OC levels were between 1.89% and 2.61%. Heavy metal concentrations were within regulatory limits, with As ranging from 0.000 to 0.550 mg/kg, Cu from 1.027 to 7.055 mg/kg, Cd from 0.039 to 0.710 mg/kg, Cr from 0.154 to 0.427 mg/kg, and Pb from 0.000 to 0.113 mg/kg. Though they have not exceeded the hazardous levels, long-term accumulation could pose risks to soil health and agricultural viability. The study highlights the emergent threat of soil degradation due to salinity and heavy metal contamination, which restricts land productivity and contributes to food insecurity. It recommend that policymakers incorporate soil health assessments into land management strategies, administer environmental regulations, and implement remediation measures. Continuous monitoring and sustainable soil management practices are essential to maintaining soil fertility, ensuring food security, and preserving ecosystem balance in Kurugu and beyond.

Keywords: *salinity, landuses, land produvtivity, eco system, kurugu*

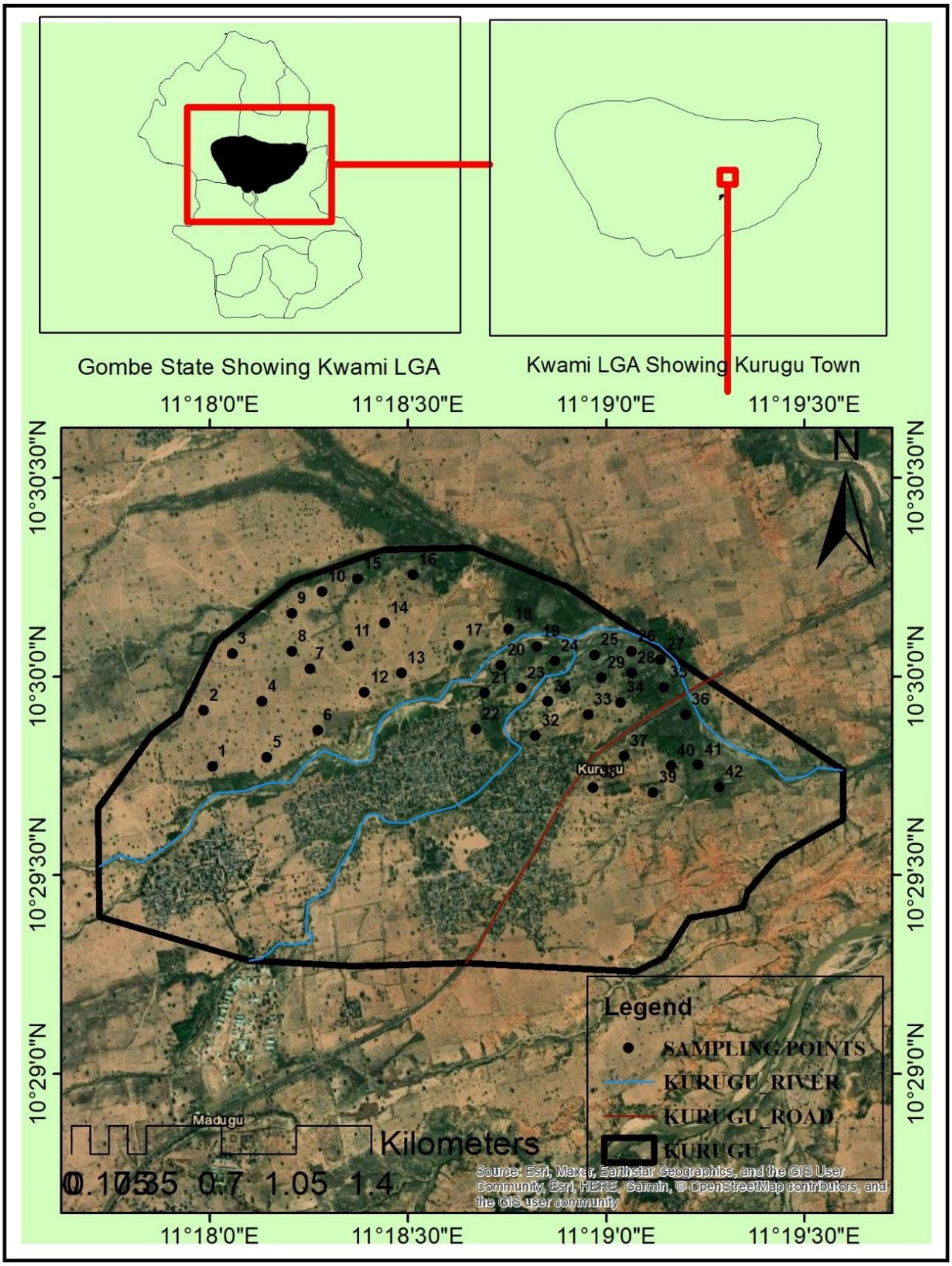
INTRODUCTION

Soil salinity is widely recognized as a growing threat to soil health, with significant implications for agricultural productivity and ecosystem sustainability (Rengasamy, 2016). In semi-arid and arid regions, soil salinization adversely affects crop diversity, plant growth, soil quality, and food security (Abdennour et al., 2020). The development of soil salinity is influenced by a combination of natural and anthropogenic factors, including unsustainable agricultural practices, inadequate drainage systems, and regional climatic and topographic conditions (Dagar et al., 2019). Additionally, factors such as soil moisture, temperature extremes, and limited seasonal rainfall exacerbate salinization processes (Tomaz et al., 2020; Hopmans et al., 2021).While natural processes contribute to soil salinity, human activities, particularly irrigated agriculture, significantly accelerate these processes (Litalien & Zeeb, 2020). Soil salinity is primarily characterized by elevated concentrations of sodium (Na^+) and chloride (Cl^-) ions. Sodicity, a related condition, occurs when exchangeable cations in the soil solution are dominated by excessive Na^+, leading to soil structure degradation and reduced permeability (Litalien & Zeeb, 2020). Salinity not only impairs plant growth by disrupting water and nutrient uptake but also deteriorates soil physical properties, further compromising agricultural productivity (Munns et al., 2019). Enzymatic mechanisms in root cell membranes, which actively exclude Na^+ and Cl^- ions, are often overwhelmed under high salinity conditions, leading to toxic accumulations within plant tissues (Munns et al., 2019).The consequences of soil salinity extend beyond agricultural losses, impacting regional economies, farmer livelihoods, and environmental sustainability. Poor crop yields in saline-affected areas exacerbate food insecurity and economic instability, particularly in developing regions (Wong et al., 2010). Furthermore, salinization negatively affects critical soil properties, including microbial biomass and activity, soil organic carbon (SOC) content, and SOC decomposition rates, thereby undermining long-term soil health and ecosystem functioning (Wong et al., 2010). Understanding and mitigating soil salinity is essential for several reasons. First, it is critical for maintaining agricultural productivity and ensuring food security. By identifying salinity-related risks and implementing targeted management strategies, farmers can mitigate yield losses and enhance crop resilience (Abdennour et al., 2020). Second, addressing soil salinity can minimize economic losses for farmers and the broader agricultural sector. Accurate assessment of salinity impacts enables policymakers to allocate resources effectively, develop supportive policies, and implement interventions to reduce financial burdens (Dagar et al., 2019). Third, efficient resource management, particularly water use, is vital in salinity-affected regions. Proper irrigation practices and water resource management can prevent further salinization while optimizing agricultural output (Hopmans et al., 2021). Moreover, research on soil salinity fosters innovation in agricultural science, including the development of salt-tolerant crop varieties and improved soil management techniques (Litalien & Zeeb, 2020). Insights from such research also inform policy development, guiding land use planning, irrigation practices, and environmental conservation efforts (Tomaz et al., 2020).This study aims to evaluate the impacts of soil salinity and heavy metal contamination on ecosystem sustainability in Kurugu, Kwami Local Government Area, Gombe State, Nigeria. By assessing the extent of salinity and its effects on diverse land uses, this research seeks to contribute to the development of sustainable land management practices and policies in the region.

Materials and Methods

Area of the Study

Kurugu is a community located in Kwami Local Government Area of Gombe State, Nigeria. Geographically, it lies at approximately latitude 10°29'38.4"N and longitude 11°18'32.7"E, placing it about 27 kilometers (17 miles) from Gombe, the state capital.The region falls within the Northeastern Guinea Savannah Zone. The climate is characterized by a tropical savanna climate (Aw), with distinct wet and dry seasons. The rainy season typically spans from April to October, with annual rainfall ranging between 600 mm and 1000 mm. The dry season occurs from November to March, during which the area experiences the Harmattan—a dry and dusty northeasterly trade wind that leads to lower temperatures and reduced humidity. Temperature variations are notable throughout the year. The hot season lasts from February 17 to April 27, with average daily high temperatures exceeding 36°C (97°F). April is typically the hottest month, with average highs around 37°C (98°F) and lows near 23°C (74°F). The cool season spans from July 7 to October 10, with average daily highs below 30°C (86°F). December is usually the coolest month, with average highs of 32°C (90°F) and lows of 14°C (58°F). The Harmattan significantly influences the local climate, bringing dry and dusty conditions that can lead to reduced visibility and cooler temperatures, especially during the early mornings and evenings. These climatic conditions, combined with low humidity and high evapotranspiration rates, often result in water scarcity during the dry season. Understanding these climatic patterns is crucial for agricultural planning, water resource management, and overall livelihood strategies in Kurugu and the surrounding areas. en.wikipedia.org (2025) weatherspark.com2025



Fig, Map of the study area showing sampling locations across the land uses of KURUGU

Experimental Design and Soil Sampling

Soil samples were collected from various land use types—agricultural fields, grazing lands, and residential areas—using a systematic sampling approach. A total of 42 composite soil samples were taken from the topsoil layer at a depth of 0–20 cm, where most biological and chemical activities occur. A composite sample consisted of five subsamples collected from a 10 m × 10 m quadrant to ensure representativeness. The samples were dried in the air, passed through a sieve with 2-mm mesh, and kept in labeled polythene bags for laboratory analysis. (Huluka and Miller, 2014; Sikora and Moore, 2014).

Determination of Soil Physicochemical Properties

Soil pH

Soil pH was determined using a digital pH meter (Jenway 3510) in a 1:2.5 soil-to-water suspension (Huluka and Miller, 2014; Sikora and Moore, 2014).

Electrical Conductivity (EC)

EC was measured using a conductivity meter (Hanna HI 9835) in a 1:5 soil-to-water extract to assess soil salinity levels (Ma., et,al). (Huluka and Miller, 2014); Sikora and Moore, 2014)

$$SAR = \frac{Na^{+}}{\sqrt{1/2(Ca^{2+} + Mg^{2+})}}$$

Bulk Density

Bulk density was determined using the core method, where undisturbed soil cores were collected, oven-dried at 105°C for 24 hours, and weighed (Blake & Hartge, 1986).

Organic Matter (OM) and Organic Carbon (OC)

OM content was determined using the loss-on-ignition method at 550°C for 4 hours (Nelson & Sommers, 1996). OC was calculated by multiplying OM by a factor of 0.58 (Walkley & Black, 1934).

Determination of Heavy Metals

Heavy metals (As, Cu, Cd, Cr, and Pb) were examined with inductively coupled plasma mass spectrometry (ICP-MS, PerkinElmer NexION 350D) following acid digestion using a combination of HNO_3, $HClO_4$, and HF (USEPA Method 3052). The detection limits for the metals were: As at 0.001 mg/kg, Cu at 0.005 mg/kg, Cd at 0.002 mg/kg, Cr at 0.003 mg/kg, and Pb at 0.005 mg/kg. To ensure accuracy and precision, quality control measures involved using certified reference materials (CRMs) and blank samples (USEPA, 1996),(Radojevic, et,al. 2005).

Data Analysis

Descriptive statistics (mean, standard deviation, and range) were used to summarize the data. The results were compared with regulatory limits set by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) to assess potential ecological and health risks. Spatial distribution maps of heavy metals and salinity levels were generated using ArcGIS 10.8 to visualize contamination hotspots.

Result and Discussion

Soil pH and Electrical conductivity

Soil pH is a key factor affecting nutrient availability and soil health (Hem, 1985). Soil sample analysis showed that pH values in the study area locations ranged from 6.87 (L12 and, L19) to 7.99, with a mean of 7.31 (L1, L17, L21, L31, and L41) and they varied from locations. All these values are within the acceptable range set by the WHO standard (6.5–8.5) (WHO, 2006; 2017; USEPA, 1996; 2005; 2019; FAO, 1999; 2008). This discovery is consistent with the studies conducted by Du et al. (2020) and Li et al. (2019), which highlighted the impact of soil characteristics like pH buffering capacity, organic matter, and texture on agricultural productivity. The values of Electrical Conductivity (EC) in the locations ranged from 137 to 915 µS/cm (L12, L19) (L2, L18, L32, L40), all of which fall short of the recommended guidelines (USEPA, 1996; 2005; 2019; WHO, 2006; 2017; FAO, 1999; 2008). This suggests that soil salinity levels do not have a major effect on crop productivity. Olajire and Imeokparia (2001) emphasized that EC serves as a crucial measure of dissolved salts in soil, while Hutton (1983) pointed out that high levels of EC can be harmful. The values documented in this study are, nonetheless, below the WHO guideline of 1500–3000 µS/cm, indicating that there are no significant salinity-related concerns.

Bulk Density and Organic Carbon

The bulk density values varied from locations 1.18 g/cm³ (L3, L34) to 1.74 g/cm³ (L8), retaining within the acceptable limits established by FAO (1999; 2008), WHO (2006; 2017), and USEPA (1996; 2005; 2019). The values imply that the soil's structure and porosity are appropriate for farming activities. The average organic carbon content in the locations ranged from 1.89% (L9, L12, L13, L19, L20, L25, L38) to 2.61% (L7, L24), affecting soil fertility and crop yield. These figures correspond to the acceptable standards (USEPA, 1996; 2005; 2019; FAO, 1999; 2008; WHO (2006; 2017) reinforces the importance of organic carbon in sustaining soil quality.

Organic Matter and Agricultural Productivity

The levels of organic matter in the locations were between 3.26% (L9, L12, L13, L19, L20, L25, L38) and 4.50% (L7, L24), which are within the recommended limits (FAO, 1999; 2008; WHO, 2006; 2017; USEPA, 1996; 2005; 2019). This aligns with the conclusions of Lal (2014), who stressed that Soil Organic Matter (SOM) is essential to soil health, fertility, and agricultural productivity as a whole.

Samples/ Location1-42	pH	E. C. (µS/cm)	Bulk density (g/cm³)	Organic Carbon (%)	Organic matter (%)
L1	7.99	429	1.33	2.34	4.03
L2	7.76	915	1.44	2.19	3.78
L3	7.87	534	1.18	2.28	3.93
L4	6.89	699	1.54	2.55	4.40
L5	7.31	435	1.33	2.37	4.09
L6	7.39	398	1.61	2.10	3.62
L7	7.68	399	1.55	2.61	4.50
L8	7.17	319	1.74	2.16	3.72
L9	7.25	241	1.73	1.89	3.26
L10	7.16	255	1.71	1.92	3.31
L11	6.98	333	1.70	2.13	3.67
L12	6.87	137	1.67	1.89	3.26
L13	7.25	241	1.73	1.89	3.26
L14	7.31	435	1.33	2.37	4.09
L15	7.39	398	1.61	2.10	3.62
L16	6.98	333	1.70	2.13	3.67
L17	7.99	429	1.33	2.34	4.03
L18	7.76	915	1.44	2.19	3.78
L19	6.87	137	1.67	1.89	3.26
L20	7.25	241	1.73	1.89	3.26
L21	7.99	429	1.33	2.34	4.03
L22	6.89	699	1.54	2.55	4.40
L23	7.31	435	1.33	2.37	4.09
L24	7.68	399	1.55	2.61	4.50
L25	7.25	241	1.73	1.89	3.26
L26	7.39	398	1.61	2.10	3.62
L27	6.98	333	1.70	2.13	3.67
L28	6.89	699	1.54	2.55	4.40
L29	7.31	435	1.33	2.37	4.09
L30	7.16	255	1.71	1.92	3.31
L31	7.99	429	1.33	2.34	4.03
L32	7.76	915	1.44	2.19	3.78
L33	6.98	333	1.70	2.13	3.67
L34	7.87	534	1.18	2.28	3.93
L35	7.16	255	1.71	1.92	3.31
L36	6.98	333	1.70	2.13	3.67
L37	7.31	435	1.33	2.37	4.09
L38	7.25	241	1.73	1.89	3.26
L39	7.39	398	1.61	2.10	3.62
L40	7.76	915	1.44	2.19	3.78
L41	7.99	429	1.33	2.34	4.03
L42	6.89	699	1.54	2.55	4.40
Mean	7.28	4.295	1.52	2.25	4.04
Min mean	6.87	137	1.18	1.18	3.26
Max mean	7.99	915	1.74	2.61	4.50
Std dev	0.44	203.6	0.15	0.22	0.39
Stds err	0.07	31.4	0.02	0.03	0.06
Cv	5.05%	47.08%	11.27%	10.17%	10.18%

NB: L – Location

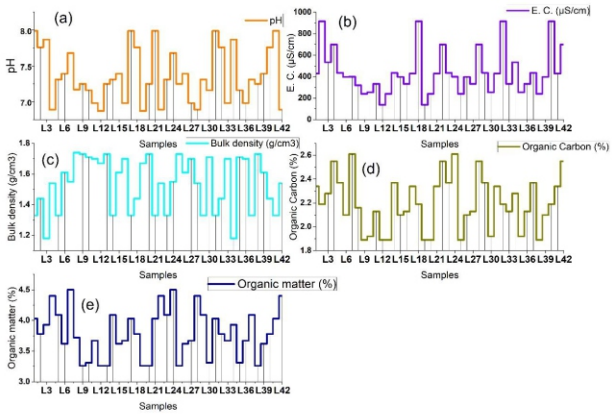
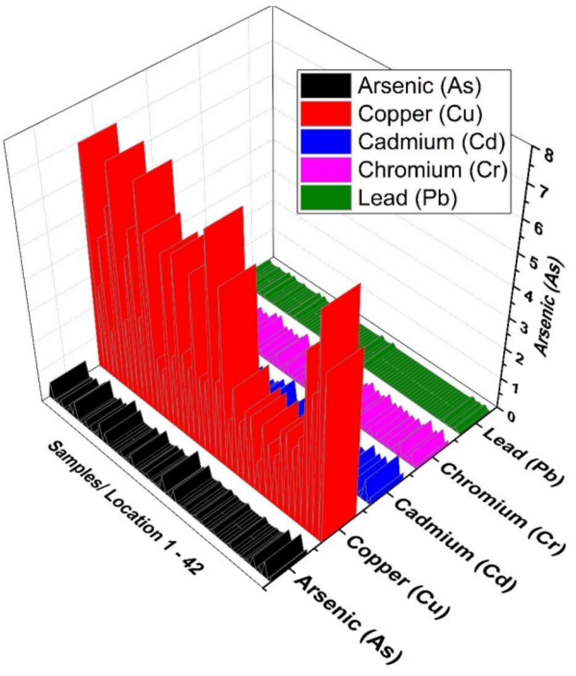


TABLE 2. HEAVY METALS CONCENTRATION OF SOIL IN THE STUDY AREA

Samples/ Location1-42	Elemental Analysis (Mg/kg)				
	Arsenic (As)	Copper (Cu)	Cadmium (Cd)	Chromium (Cr)	Lead (Pb)
L1	0.178	5.434	0.256	0.166	0.000
L2	0.550	7.055	0.710	0.403	0.113
L3	0.210	4.498	0.138	0.225	0.064
L4	0.356	5.662	0.365	0.427	0.113
L5	0.097	2.854	0.316	0.154	0.000
L6	0.065	2.374	0.454	0.202	0.000
L7	0.000	2.740	0.049	0.166	0.000
L8	0.146	2.648	0.079	0.202	0.000
L9	0.000	1.667	0.039	0.225	0.000
L10	0.000	1.895	0.039	0.178	0.000
L11	0.129	2.397	0.178	0.332	0.000
L12	0.000	1.027	0.039	0.166	0.000
L13	0.065	2.374	0.454	0.202	0.000
L14	0.129	2.397	0.178	0.332	0.000
L15	0.000	1.895	0.039	0.178	0.000
L16	0.097	2.854	0.316	0.154	0.000
L17	0.000	1.667	0.039	0.225	0.000
L18	0.356	5.662	0.365	0.427	0.113
L19	0.146	2.648	0.079	0.202	0.000
L20	0.550	7.055	0.710	0.403	0.113
L21	0.065	2.374	0.454	0.202	0.000
L22	0.065	2.374	0.454	0.202	0.000
L23	0.178	5.434	0.256	0.166	0.000
L24	0.129	2.397	0.178	0.332	0.000
L25	0.000	2.740	0.049	0.166	0.000

L26	0.356	5.662	0.365	0.427	0.113
L27	0.065	2.374	0.454	0.202	0.000
L28	0.178	5.434	0.256	0.166	0.000
L29	0.000	1.667	0.039	0.225	0.000
L30	0.000	1.895	0.039	0.178	0.000
L31	0.356	5.662	0.365	0.427	0.113
L32	0.550	7.055	0.710	0.403	0.113
L33	0.097	2.854	0.316	0.154	0.000
L34	0.178	5.434	0.256	0.166	0.000
L35	0.210	4.498	0.138	0.225	0.064
L36	0.065	2.374	0.454	0.202	0.000
L37	0.550	7.055	0.710	0.403	0.113
L38	0.356	5.662	0.365	0.427	0.113
L39	0.000	1.667	0.039	0.225	0.000
L40	0.210	4.498	0.138	0.225	0.064
L41	0.097	2.854	0.316	0.154	0.000
L42	0.035	0.148	0.037	0.026	0.013
Mean	0.1745	3.7100	0.2834	0.2568	0.0330
Min mean	0.000	1.027	0.039	0.154	0.000
Max mean	0.550	7.055	0.710	0.427	0.113
Std dev	0.1768	1.8837	0.2149	0.1006	0.0490
Stds errr	0.0273	0.2907	0.0332	0.0157	0.0076
Cv	101.33%	50.77%	75.82%	39.18%	148.41%



Soil contamination with heavy metals is currently considered as one of the most serious environmental problems due to heavy metal persistence and toxicity, having a great impact as the development of areas without soil in good condition is difficult (Salazar and Pignata 2014). Concentrations of heavy metals in soils can result from natural or anthropogenic factors, with the latter being most common. Metals are usually non degradable and become toxic if they exceed their threshold level, which poses a threat to biological life. Heavy metals may be bound or sorbed by particular natural substances, which may increase or decrease mobility (Dube et al. 2001).

Arsenic (As): The mean concentrations ranged from 0.000 to 0.550 mg/kg with significant differences observed in samples from L2 compared to other locations. The highest mean concentration of arsenic (0.550 mg/kg) was found in samples from locations L2, L20, L32, L37, and L42. In contrast, other locations had arsenic levels as low as 0.000 mg/kg. The mean arsenic concentrations in the samples were below the allowable limits set by the FAO (1999, 2008), WHO (2006, 2017), and USEPA (1996, 2005, 2019), indicating a relatively low risk of contamination but still highlighting some localized environmental impact.

Copper (Cu) The mean concentrations ranged from l 1.027 mg/kg to (7.055 mg/kg) was observed at location as L12, and higher in L2, significantly higher than other locations such where the mean was as Similar to arsenic, copper concentrations in the samples were within the allowable limits set by WHO, USEPA, and FAO, which there would not be disruption in nutrient cyclingor toxicities in plant and suggesting no immediate risks from copper contamination.

Cadmium (Cd): The mean concentrations ranged from L39 (0.039 mg/kg) to highest 0.710 mg/kg observed in the same locations (L2, L20, L32, L37, and L42),were also lower than the allowable thresholds set by the FAO, WHO, and USEPA. Although cadmium concentrations were within safe levels, its presence could still have adverse effects on the environment and human health if bioaccumulation occurs.visa vis with with lower level thre would be soil structure alteration that would affectsinfiltration and root growth

Chromium (Cr): The lowest chromium concentration ranged from (0.154 mg/kg) L41 and highest mean chromium concentration (0.427 mg/kg) was observed across locations from L4, L18, L26, L31, and L38. Again, chromium levels were below the allowable limits set by FAO, WHO, and USEPA, indicating that there is no immediate concern regarding chromium contamination in the studied area.

Lead (Pb): The lowest Lead concentration ranged 0.000 mg/kg to mg/kg) L41 and highest mean chromium concentration 0.113 mg/kg mg/kg) was observed across these locations L2, L4, L18, L20, L26, L31, L32, L37, L38, and L42. Lead levels were generally low, with no significant difference in concentrations across many sites, although L2, L4, and others showed some variation. Lead concentrations in all samples were below the set permissible limits, suggesting that lead contamination does not pose a significant risk in this area, although prolonged exposure could still be harmful.

Conclusion

The study on heavy metal contamination and soil salinity in Kurugu, Gombe State, Nigeria, reveals environmental challenges. Although soil pH, bulk density, and organic matter content are stable, heavy metals like arsenic, copper, cadmium, chromium, and lead are present below permissible limits, posing risks to ecosystem sustainability. The spatial distribution of these contaminants, particularly in hotspots locations like L2, L20, L32, L37, and L42, suggests localized environmental impacts that could escalate if not addressed. Although soil salinity levels, as measured by electrical conductivity, were below critical thresholds, the combination of salinity and heavy metal contamination poses a latent threat to agricultural productivity, soil biodiversity, and groundwater quality. The findings underscore the need for proactive measures to mitigate these environmental stressors and ensure the long-term sustainability of the ecosystem in Kurugu.

Recommendations

1. Regular Monitoring and Assessment Set up a regular program for monitoring soil and water quality to observe changes in heavy metal concentrations and salinity levels. This will assist in recognizing emerging contamination hotspots and guiding prompt interventions.

2. Sustainable Agricultural Practices Encourage the use of sustainable farming methods, including crop rotation, organic agriculture, and salt-tolerant crop varieties, to lessen the impact of soil salinity and decrease dependence on chemical fertilizers that can lead to heavy metal accumulation.

3. Remediation of Contaminated Sites Employ remediation techniques like phytoremediation (utilizing plants to take up heavy metals) and soil amendments (such as lime or organic compost) to lower the levels of heavy metals in impacted regions.

4. Awareness and teaching Implement community awareness initiatives aimed at informing farmers and residents about the dangers of heavy metal contamination and soil salinity, along with optimal practices for sustainable land management.

4. Promote the creation and application of environmental policies that control industrial activities, mining, and waste disposal to avert additional contamination of soil and water resources.

5. Research and Collaboration Promote additional studies on the long-term effects of heavy metals and salinity on soil health and ecosystem sustainability. Work together with regional universities, research organizations, and governmental bodies to create inventive solutions customized to the unique challenges of the area
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6. Water resources management Resources Enhance water management methods to lower the likelihood of salinity accumulation, including the improvement of drainage systems and the promotion of effective irrigation methods to reduce waterlogging and salt buildup.

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